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Data-driven approach for highlighting priority areas for protection in marine areas beyond national jurisdiction

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ABSTRACT

One of the aims of the United Nations (UN) negotiations on the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (ABNJ) is to develop a legal process for the establishment of area-based management tools, including marine protected areas, in ABNJ. Here we use a conservation planning algorithm to integrate 55 global data layers on ABNJ species diversity, habitat heterogeneity, benthic features, productivity, and fishing as a means for highlighting priority regions in ABNJ to be considered for spatial protection. We also include information on forecasted species distributions under climate change. We found that parameterizing the planning algorithm to protect at least 30% of these key ABNJ conservation features, while avoiding areas of high fishing effort, yielded a solution that highlights 52,545,634 km^2 (23.7%) of ABNJ as high priority regions for protection. Instructing the planning model to avoid ABNJ areas with high fishing effort resulted in relatively minor shifts in the planning solution, when compared to a separate model that did not consider fishing effort. Integrating information on climate change had a similarly minor influence on the planning solution, suggesting that climate-informed ABNJ protected areas may be able to protect biodiversity now and in the future. This globally standardized, data-driven process for identifying priority ABNJ regions for protection serves as a valuable complement to other expert-driven processes underway to highlight ecologically or biologically significant ABNJ regions. Both the outputs and methods exhibited in this analysis can additively inform UN decision-making concerning establishment of ABNJ protected areas.

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1. Introduction

Marine areas beyond national jurisdiction (ABNJ) (i.e. marine regions inclusive of the water column, seabed, and subsoil beyond the limits of national jurisdiction, which is usually outside the 200 nautical mile limit of a nation's Exclusive Economic Zone (EEZ)) cover nearly half of the Earth's surface and support a high abundance and diversity of life [1]. Human activity and industry have grown substantially in ABNJ since the region was defined in 1982 by the United Nations Convention on the Law of the Sea (UNCLOS). Industrial fishing, for example, is now estimated to occur in 48% of ABNJ [2]. This footprint may grow as new types of fisheries (e.g. fishing for mesopelagic fish) become technically feasible in ABNJ and fisheries extend deeper into new domains [3]. Marine shipping, as measured by increases in container port traffic, has risen by approximately 1600% since UNCLOS was signed in 1982 [4–6]. This growth in the long-established fishing and shipping industries in ABNJ is mirrored by activity and interest in other emerging marine industries including prospecting for marine genetic resources, ocean mining, and the expansion of undersea data cable infrastructure. More than one million square kilometers of ABNJ seabed have, for example, been gazetted as exploratory mining claim areas and may soon be commercially mined [7–9]. Potential novel future uses of ABNJ (e.g. open ocean mariculture, sea-steading [10]) could even further increase the footprint of human activity in ABNJ regions.

Despite this recent growth in anthropogenic activity in ABNJ, the region still harbors the vast majority of the ocean's few remaining marine wilderness areas [11]. ABNJ are also home to unique biodiversity [12], which has been suggested to be at higher risk than biodiversity within national waters [13]. This observed intersection of increasing human activity within historically less disturbed, at-risk marine regions, creates an imperative for considering how spatial management tools, such as marine protected areas (MPAs), could be employed to constructively manage the future of ABNJ biodiversity and marine resources. The value of MPAs as one important tool in a broader management toolkit to protect biodiversity in increasingly busy marine contexts is well known in coastal marine regions, although the effectiveness of these MPAs appears contingent on their design and management [14–18]. As elsewhere, consideration of the use of tools such as MPAs in ABNJ is doubly imperative considering that all portions of ABNJ, from the deep sea to pelagic megafauna, are being rapidly influenced by climate change impacts on ocean temperature [19,20], deoxygenation [21], and chemistry [22,23]. MPAs appear to play a role in increasing resistance or resilience to climate change effects on ocean ecosystems [24–27].

Data-driven planning tools to guide the design of MPAs have been developed and deployed extensively in the context of many marine coastal regions [28,29]. Planning for MPAs in ABNJ, however, is a process more in its infancy. The relative newness of MPA planning efforts and planning tool research in ABNJ, at least in part, derives from the historical paucity of legal mechanisms and political opportunity to establish ABNJ MPAs, particularly in non-polar ABNJ regions. However, a possible pathway for establishing MPAs in ABNJ is currently the subject of ongoing negotiations within the United Nations (UN) [8,30]. The consideration of area-based management tools, including MPAs, is one of the four focal thematic areas for these negotiations on an international legally binding instrument under the UN Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ) [31,32].

Another historical stumbling block for driving forward MPA planning in ABNJ has been the previous scarcity of spatial data on the abundance and distribution of biodiversity and habitats. While data remain far from complete, recent improvements in toolkits for remote sensing, marine database integration, biologging, and biodiversity range modeling have significantly expanded our understanding of ABNJ biodiversity [33–36]. With these new toolkits, the density of biological and physical data from ABNJ has increased substantially in the last half century [37]. This ever-improving insight into patterns of biodiversity in ABNJ is made dynamic by a variety of new data products that forecast how biodiversity is likely to respond to climate change [35,38–41]. The ability to conduct rigorous spatial planning for area-based management in ABNJ is further enabled by the recent emergence of new data products that provide high-resolution visibility into how key human industries, especially fishing, are using ABNJ [42–45]. These data sources provide spatially explicit insight into how human industry is interacting with biodiversity in ABNJ [46] and which portions of ABNJ are most important to people with respect to currencies such as profit and food capture [2]. Collectively, this increase in the quality and quantity of data on biodiversity and human use of ABNJ provides the needed raw ingredients for robust MPA planning in ABNJ.

There has been considerable productive research and political conversation about global goal setting for MPA establishment. In particular, there has been significant focus on the amount of ocean or representative ocean habitats that should be protected to meet goals for biodiversity management and conservation. In 2010, the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) adopted the goal of protecting at least 10% of representative and well-connected coastal and marine areas of particular importance to biodiversity by 2020 [47]. The CBD COP will be meeting again in 2020 to reevaluate that 10% target, and there is increasing pressure from civil society and governments to increase that target to 30%. The International Union for Conservation of Nature (IUCN) adopted a 30% target to protect marine habitats [47,48], which is in line with the findings of some researchers that $\geq$ 30% protection of the sea is needed to achieve a suite of ecological and socioeconomic objectives [24]. Other researchers have suggested more ambitious targets. EO Wilson and colleagues have called for a 50% target for ocean protection [49]. Still others have suggested that a complete (100%) closure of the high seas would conserve biodiversity while simultaneously giving rise to significant increases in fishery profits and yields [50,51]. Presently, only 7.9% of the global ocean is recognized as protected by the United Nations Environment Programme [52], with only 2.5% of the ocean included in highly protected MPAs [53]. Furthermore, only 1.2% of the high seas have been designated in MPAs [52] with only 0.8% identified as highly protected [53].

In this exercise, we align and combine insight from 55 layers of globally distributed data using a well-tested conservation planning tool, all towards the aim of strategically identifying key candidate areas deserving of protection in ABNJ. These data layers include information on biological diversity, threatened species, habitat diversity, productivity, and anthropogenic use (i.e. fishing) of ABNJ. We include in the planning analysis information on the contemporary distribution of species (endangered and not endangered) as well as data on the forecasted future distribution of the same species in a climate-altered ocean. In this exercise, we parameterized this planning model to protect a minimum of 30% of all key conservation features to approximate goal setting congruent with the IUCN stated goal of 30% protection [48]. We assume that all areas highlighted as candidate ABNJ MPAs would be completely closed to all extractive activities, subject to the rights of indigenous peoples, in both the water column and seabed (i.e. pursuant to the IUCN MPA commitment) [48], and as such would provide the greatest benefit to biodiversity conservation [14,54].

Exploring tradeoffs is a core part of MPA planning in any context [55–57]. In this ABNJ-focused exercise, we examine the influence that avoiding protecting regions of ABNJ where there is a high level of detectable fishing effort has on the ABNJ planning solution—recognizing that fishing is an important source of income, nutrition, and jobs for stakeholders. We similarly examine potential tradeoffs involved in attempting to "climate proof" MPAs by including information on how climate change is forecasted to affect biodiversity in ABNJ.

This data-driven, algorithm-guided process for identifying potential ABNJ MPAs complements long-running planning efforts that have endeavored to identify priority areas in ABNJ principally via input from regional experts, most notably the Convention on Biological Diversityled process to identify "Ecologically or Biologically Significant Marine Areas" (EBSAs) [58–60]. We examine the overlap between the ABNJ areas highlighted by this planning algorithm and these expert-identified EBSA areas. However, our approach focuses primarily on biodiversity-associated criteria and does not consider all criteria used to define EBSAs, such as identifying unique, rare, or fragile places, which may not be co-located with areas having high biodiversity and thus deserve separate consideration.

We submit that the specific candidate MPA regions emerging from this conservation planning analysis can constructively guide and inform further conversation within the UN BBNJ negotiation process concerning specifically if and where to establish ABNJ MPAs. We also emphasize that the analytical methods themselves illuminate a highly adaptable data-driven process for undertaking ABNJ MPA decision-making that may be of service during or after these BBNJ negotiations.

2. Methods

We employed a data-driven process for identifying priority areas for potential MPA establishment in ABNJ using biological, physical, and anthropogenic (i.e. fishing effort) global datasets and the systematic conservation planning tool *prioritizr* [61]. *Prioritizr* uses integer linear programming techniques to select a minimum set of planning units that meet or exceed the conservation planning targets while minimizing the costs associated with the planning units selected. *Prioritizr* is an R package that derives an analytical solution to this "minimum set problem" that has been historically solved heuristically, i.e. imprecisely, using Marxan [62,63]. All data and code for the analysis, including the custom *bbnj* R package [64], mapping application and analytical scripts are available at: 10.5281/zenodo.3554536.

2.1. Study region

We defined the ABNJ study region as ocean areas outside EEZ boundaries obtained from www.marineregions.org [65]. For the purposes of this analysis, we elected to exclude from ABNJ the Mediterranean Sea given its unique biogeography and legal regime [66,67] and to include the ocean surrounding Antarctica (i.e. including the ocean within 200 nm of the Antarctic coastline); however we note the unique jurisdiction of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in these waters [68,69]. The total resultant ABNJ region used in this analysis was 221,732,132 km^2.

This ABNJ study region was converted to an equal-area grid in Mollweide projection, resulting in 88,312 cells, each approximately 50 km $\times$ 50 km ($\sim$2500 km^2), which matches the half degree cell resolution near the equator of the AquaMaps input biodiversity layers. Each cell, or planning unit in *prioritizr* parlance, represents a discrete area that can be included or excluded from a protected area solution using the conservation planning algorithm and could be managed independently or in combination with the management of other areas.

2.2. General data parameters

The following seven core classes of spatially explicit data were drawn into this ABNJ MPA planning analysis: species richness, species IUCN extinction risk, seamounts, hydrothermal vents, benthic habitat heterogeneity, net primary production, and fishing effort. For species richness and species IUCN extinction risk data, we included, as described further below, both contemporary data and data that forecasts species distributional changes by the year 2100 (Table S1). A total of 55 final data layers were derived from these seven core data products for inclusion in the planning algorithm: species richness (23 layers of taxonomically grouped data), species richness in 2100 (23 layers of taxonomically grouped data), species IUCN extinction risk (1 layer summed for all species), species IUCN extinction risk in 2100 (1 layer summed for all species), seamounts (3 layers grouped by summit depth), hydrothermal vents (1), benthic habitat heterogeneity (1), net primary production (1), and fishing effort (1). All data layers were clipped to the ABNJ study region (i.e. data overlap with EEZs was removed), projected into the equal-area Mollweide projection and resampled to the planning unit grid to determine how much of each feature or activity occurs in each planning unit. All data layers, except fishing effort, were included in our implementation of *prioritizr* as conservation features to be prioritized for inclusion in the MPA planning solution. Fishing effort was used as the cost layer in *prioritizr* to direct the algorithm to avoid pulling into the MPA planning solution regions that are intensively used by fishing fleets in ABNJ.

2.2.1. Conservation features data

2.2.1.1. Species richness. In this analysis, species richness was derived from AquaMaps standardized global species distribution maps [35]. AquaMaps is an environmental envelope model that generates predictions about relative environmental suitability by relating species habitat preferences to environmental parameters such as depth, primary production, temperature, sea ice concentration, and salinity. The model predicts relative probability of species occurrence (0–1) at 0.5° cell resolution. We incorporated AquaMaps data for the 12,013 marine species that had a probability of occurrence $\geq$0.5 in at least one ABNJ planning unit, and applied that 0.5 probability threshold to convert relative probability of occurrence from continuous to binary (i.e. present or absent). In each planning unit, species richness was then derived by summing the number of species present [27,41,70,71].

Species richness data was then aggregated across these 12,013 species into 23 major taxonomic groups, each of which was included as a separate, equally weighted conservation feature in *prioritizr*. Taxonomic grouping for this analysis was defined similar to Tittensor et al., 2010 [72], with modifications intended to capture the functional, ecological, and socio-economic importance of species groups (Table S2, Fig. S1). Aggregating in this fashion is intended to create some balance in priority setting between importance placed on species richness and species evenness, while maintaining computational tractability. This collection of species in AquaMaps includes many major groups of marine species (i.e. fishes, marine mammals, marine invertebrates, and seagrasses; full list in Table S2) but certainly not all major taxa are covered (e.g. seabirds are not included).

In addition to current species distribution data, we also incorporated AquaMaps projected species distributions for the year 2100, which predicts the relative probability of occurrence in 2100 given global climate change conditions described under IPCC SRES A2 scenario [35]. We applied the same method as described above to calculate species richness from distribution maps using the AquaMaps 2100 model.

2.2.1.2. Species extinction risk. Species extinction risk data were obtained from IUCN Red List [73]. The Red List Sum (RLS) was then calculated by multiplying the number of taxa in each red list category by the category weight (0 for Least Concern, 1 for Near Threatened, 2 for Vulnerable, 3 for Endangered, and 4 for Critically Endangered) [74]. Using the AquaMaps range maps and $\geq$0.5 probability of occurrence threshold, we summed the products for all assessed species present in each planning unit cell. Data deficient species were excluded.

The same methods were applied to calculate RLS for species using forecasted distributions from the 2100 AquaMaps range maps [35].

2.2.1.3. Seamounts. Seamount distributions were acquired from altimetry-derived gravity data [75]. Seamounts are important habitat features known to be hotspots of both pelagic and benthic biodiversity in the open ocean [76–78]. Three representative categories for seamount summit depth (0–200 m, 201–800 m, >801 m) were applied to this dataset to achieve coarse representation of seamounts at different water depths in ABNJ MPA scenario planning because seamount summit depth is thought to be associated with different species assemblages [77]. Seamount counts for each of these three defined depth classes was calculated for each planning unit and each depth class was considered as an individual conservation feature.

2.2.1.4. Hydrothermal vents. Biological communities at hydrothermal vents display a high degree (~85%) of species endemism and high, sustained rates of species discovery [12]. Hydrothermal vent distribution was obtained from the InterRidge Vents Database Ver. 3.4 [79] and vent count (including active-known, active-inferred, and inactive vents) was calculated for each planning unit.

2.2.1.5. Benthic habitat heterogeneity. A measure of benthic habitat heterogeneity, as developed by Harris and Whiteway 2009 [80], was included as a conservation feature in the analysis to capture the value of conserving areas with diverse representation of benthic habitat types often in small areas. This measure uses global datasets of seabed bathymetry, sediment thickness, geomorphology, primary production, and bottom water properties to classify the seafloor into 11 different categories or "seascapes" and then applies a focal-variety analysis to identify areas where the most seascape diversity occurs [80]. Areas with high seascape diversity were prioritized in this analysis.

2.2.1.6. Net primary production. Net primary production was drawn into this planning exercise as ocean primary production and derivatives of these measurements are known to play a role in shaping the behavior of ABNJ species as well as patterns of species richness in the water column and deep ocean [81–84]. Net primary production was calculated as the mean of the standard Vertically Generalized Production Model (VGPM) derived from VIIRS satellite data by Oregon State University [85,86]. The average value was calculated from the monthly VGPM product spanning from 2013-02-01 to 2019-01-31 at a spatial resolution of 1/12 decimal degrees.

2.2.2. Fishing effort data

We used a global dataset of fishing effort (expressed in kilowatt-hours) as the cost layer in *prioritizr* to account for the potential opportunity cost of foregone commercial fishing activity in a planning unit if it were to be protected and closed to fishing. Fishing effort data from 2016 was obtained from Sala et al., 2018 [2,43], which used automatic identification systems (AIS) and vessel monitoring systems (VMS) data, coupled with machine learning filtering functions, from the Global Fishing Watch database to identify the global distribution of fishing effort in ABNJ. For this analysis, we used only the top quartile of fishing effort (i.e. $>$ 112,774 KWH) to drive the algorithm away from including planning units in the conservation solution that had especially high levels of fishing effort.

2.3. Conservation planning analysis

2.3.1. Conservation planning algorithm

For this application of the conservation planning tool *prioritizr*, we elected to use the minimum set objective function, which seeks to minimize the cost of the solution (here minimizing solution overlap with high effort fishing areas) whilst ensuring that all conservation feature targets are met [61]. We applied a 30% target to each of 54 conservation features, which were derived from the seven core datasets described above. Targets were calculated by taking 30% of the summed values of all cells for each conservation feature (rather than taking 30% of spatial extent). Therefore, for each conservation feature, high-value cells are prioritized for inclusion in the protected area solution; however, the algorithm also applies the principle of complementarity, where potential protected area sites are evaluated jointly to maximize the representation of conservation features across a region [87,88]. We utilized the Gurobi commercial software (free academic licenses available) as the optimization engine for *prioritizr* to solve the conservation problem once parameterized.

2.3.2. Analysis of influence of fishing effort data

In order to better understand how the inclusion of fishing effort data shaped the candidate ABNJ MPA solution generated, we conducted and compared a separate run of the model that excluded fishing effort data, and instead used planning unit area as the cost. This model run included all of the same conservation feature targets as described above.

2.3.3. Analysis of influence of climate change data

We also analyzed the impact of including the climate forecast data on the conservation planning solution by comparing a run of the model that excluded 2100 projections for species richness and species IUCN extinction risk as conservation feature targets against a model run that included both contemporary biodiversity data and 2100 forecasts of biodiversity data as conservation feature targets.

2.3.4. Analysis of overlap with "Ecologically or Biologically Significant Marine Areas"

We examined the spatial overlap (amount of area overlap and number of unique intersecting regions) between the solution in this analysis and all areas identified in the expert-driven EBSA process [58] (cbd.int/ebsa; summarized into a shapefile at github.com/iobis/ebsa_np). We also examined overlap between the solution and a subset of EBSAs that were specifically described as having high biological diversity (i.e. all EBSAs that were rated as "high" by experts against EBSA criteria 6 "biological diversity"; excluding EBSAs for which there was no ranking provided for criteria 6). We emphasize that while these comparisons are insightful, it is important to note that our approach does not consider all of the same seven criteria used for identifying EBSAs [58].

2.3.5. Analysis of proximity to exclusive economic zones

Given the potential possible influence of ABNJ MPAs located near EEZs with respect to delivery of spillover services, such as enhanced fishery productivity [50,89,90], we also examined the number of EEZ boundaries contiguous with the proposed MPA solution in this analysis. Sovereign EEZ boundaries were obtained from marineregions.org [65], rasterized to the Mollweide ~50 km $\times$ 50 km study grid and converted to vector for extracting shared borders along the EEZ-ABNJ boundary. We also classified the wealth status of all nations whose EEZs shared borders with our solution, following designations by World Bank, aggregated sensu McCauley et al., 2018 [91] (i.e. "lower-income nations" collectively refers to countries that were classed as lower-middle income or low income and "higher-income nations" refers to those that were classified as upper-middle income or high income by the World Bank).

2.3.6. Sensitivity analysis

We examined the sensitivity of the results yielded from our implementation of the conservation planning algorithm to one of our core model assumptions - the minimum percent of each conservation feature required to be included in the solution. As described above, in this analysis the minimum target feature percentage was set to 30%. After running the model with this 30% target, we also subsequently re-ran the model at 10% intervals from 10%-100% and examined the amount of ABNJ area included in the conservation solution at each of these different target percentages.

3. Results

Implementation of this conservation planning approach as described resulted in a solution that highlighted a global total of 52,545,634 km^2 of ABNJ (or 23.7% of the total ABNJ study region) that could serve as high priority regions for MPA establishment (Fig. 1). This solution optimized inclusion of both ABNJ regions that are believed to be biodiverse now and those that are projected to be biodiverse in 2100 as climate change advances. The solution also minimizes inclusion of ABNJ regions with the highest amount of fishing effort.

The ABNJ priority regions identified in this analysis were relatively evenly distributed among the major ocean basins, with the exception of the Arctic Ocean. The largest solution area, constituting 21.3% of the overall solution area, was found in the South Pacific Ocean, with 19.2%, 18.3%, 18.2%, 13.4%, 9.5%, and 0.04% found in the South Atlantic, Indian, North Atlantic, North Pacific, Southern, and Arctic Ocean basins, respectively.

As parameterized, the algorithm required that the solution includes a minimum of 30% of each conservation feature. Twelve of the 54 conservation features just satisfied this minimum requirement (Fig. 2). The features that only met this 30% threshold are notable given the defining and constraining influence that they had upon the solution. The remaining 42 features exceeded this minimum requirement with up to 72% of a target protected (i.e. euphausiid species richness 2100) in this solution (Fig. 2).

3.1. Analysis of influence of fishing effort data

Post-hoc analyses revealed that the inclusion of high fishing effort as a cost in the conservation planning algorithm had only a relatively minor influence on the MPA solution. Overall, 73% of the solution remained the same regardless of whether fishing effort was included. When comparing the model results that did not consider fishing effort at all, relative to the model results that attempted to avoid including high fishing effort areas in the solution, 7,642,819 km^2 (3.4% of ABNJ study region) of high fishing effort area was removed from the solution and 8,596,916 km^2 (3.9% of ABNJ study region) of new area was added to the solution (Fig. 3).

3.2. Analysis of influence of climate change data

The inclusion of climate change data also appeared to have a relatively minor influence on the ABNJ MPA solution. Overall, 95% of the solution remained the same regardless of whether the data on future projections of biodiversity under climate change were included (Fig. 4). Comparisons of model results that included only contemporary biodiversity data relative to model results that included both contemporary and future biodiversity data, revealed that 1,463,786 km^2 (0.7% of ABNJ study region) of ABNJ area was removed from the solution and 1,498,937 km^2 (0.7% of ABNJ study region) of new area was added to the solution (Fig. 4).

3.3. Analysis of overlap with "Ecologically or Biologically Significant Marine Areas"

There was a significant amount of overlap between the solution highlighted in this algorithm-led planning process and ABNJ regions identified by experts as ecologically or biologically significant during the EBSA process. A total of 53 of the current 64 EBSAs that have some contact with ABNJ also had contact with the conservation planning solution generated in this analysis. A total of 15,344,831 km^2 of ABNJ were shared in common between the solution derived from this analysis and EBSAs—or 31% of the total EBSA area within ABNJ (Fig. S2). Overlap was higher when the solution highlighted in this analysis was compared against the subset of EBSA regions that were identified by experts on the basis of high biological diversity. A total of 23 of the 24 such high biological diversity ABNJ EBSAs shared some intersection with the model solution equating to a total of 3,634,748 km^2 of ABNJ—or 42% of the total high biological diversity EBSA area within ABNJ.

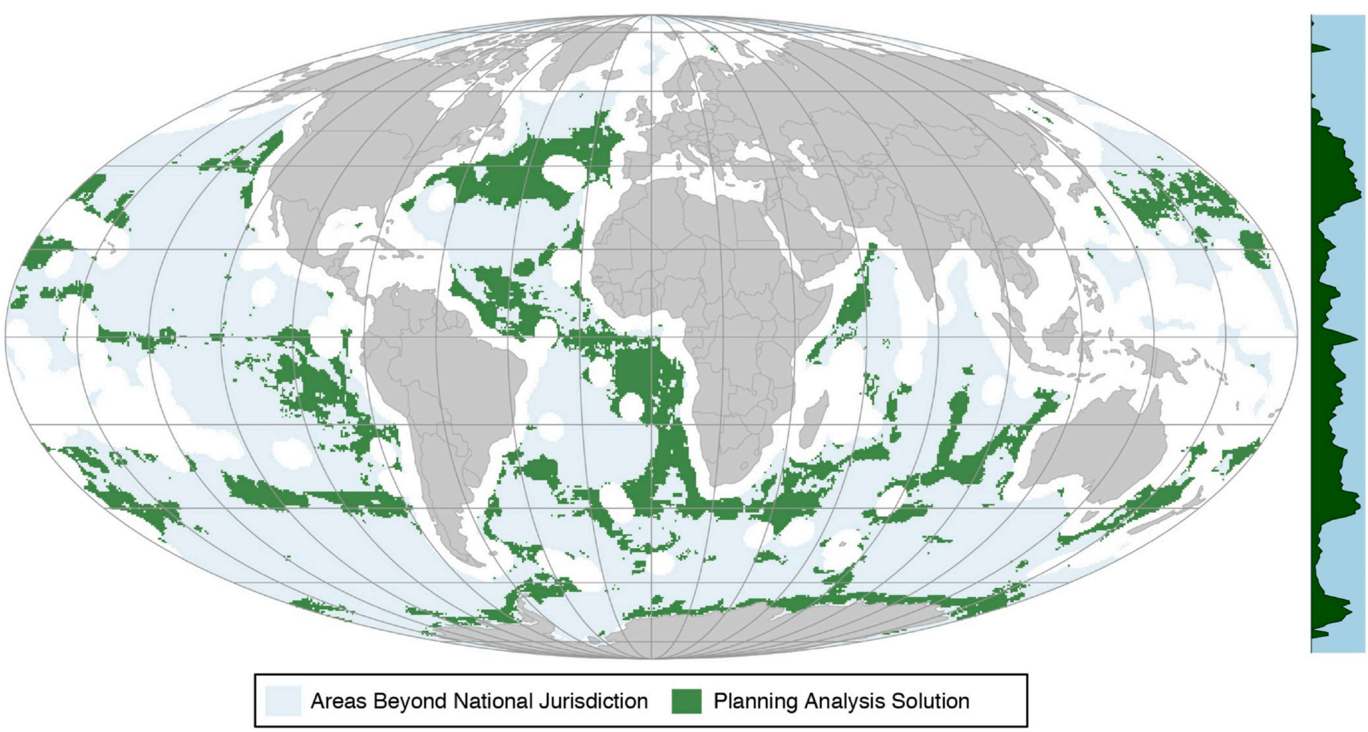

Fig. 1. Outputs from global data-driven conservation planning analysis highlighting priority areas to be considered for protection (green) in marine areas beyond national jurisdiction (ABNJ). Percentage of ABNJ protected by latitude is shown in the plot on the right margin. This planning solution includes consideration of 55 data layers exhibiting the global distribution of ABNJ species richness, endangered species, seamounts, hydrothermal vents, benthic habitat heterogeneity, marine net primary production, and fishing effort. The planning solution is parameterized to meet a minimum of 30% protection for all conservation features, to navigate away from areas of the highest fishing effort, and to simultaneously prioritize the protection of both the contemporary and forecasted future (i.e. 2100) distributions of ABNJ biodiversity. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

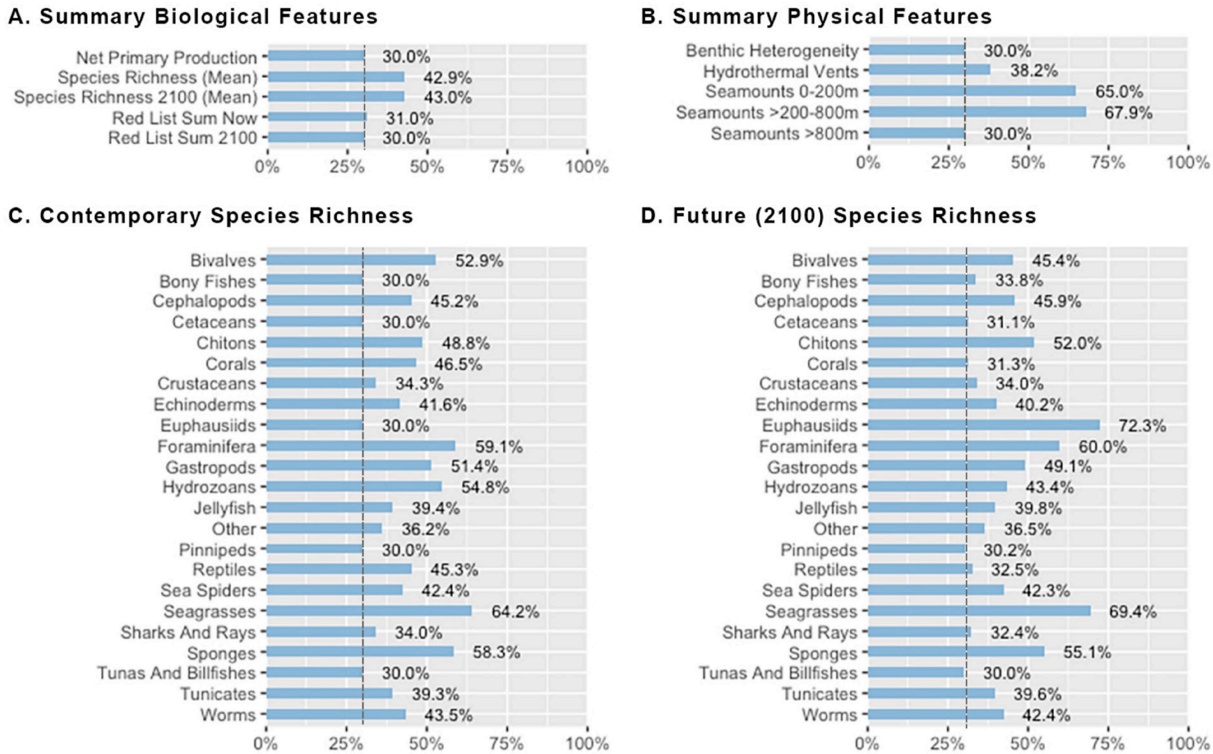

Fig. 2. Summary of percent targets conserved by the solution highlighting priority areas to be considered for protection in marine areas beyond national jurisdiction (ABNJ) (Fig. 1). A minimum target of 30% of each conservation feature target was required in this implementation of the planning algorithm (dotted vertical line). Conservation features are described in Methods and Table S2 and are grouped here as: **A**. summary biological features reporting on ocean productivity, contemporary and future (i.e. climate change 2100 forecast) aggregated species richness, and the Red List sums of endangered species; **B.** benthic physical features; **C.** contemporary species richness aggregated by major taxonomic group; and **D.** future species richness (i.e. climate change 2100 forecast) aggregated by major taxonomic group. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.4. Analysis of proximity to exclusive economic zones

In sum, 65 of the total 153 sovereign EEZs [65] contacted the ABNJ solution generated by this model resulting in 105,878 km of shared borders between the ABNJ model solution and EEZs. This amounts to 32% of the total ABNJ boundary length. Of these EEZs contacting our planning solution, 29 represented lower-income nations and 36 were classified as higher-income nations. A total of 11,174 km and 94,704 km of borders with the ABNJ solution were shared by lower-income and higher-income nations, respectively.

3.5. Sensitivity analysis

The sensitivity analysis suggested that the total area of the prioritization solution was relatively consistent with the minimum percent conservation target parameter. The area of the conservation solution scaled linearly and positively with increasing minimum required percent of conservation feature with no apparent discontinuities (Fig. S3).

4. Discussion

In this analysis we demonstrate a framework for using a state-of-the-art conservation planning algorithm to strategically synthesize spatially explicit global datasets to prioritize ABNJ areas for protection. Should the UN BBNJ negotiation process create a legal mechanism for MPA establishment, these outputs could inform the process.

In our parameterization of the conservation planning algorithm we required that all input conservation feature targets met a minimum of 30% inclusion in our candidate ABNJ MPA solution (in congruence with IUCN goal setting). Some conservation features exceeded this target considerably (Fig. 2). For example, shallow seamounts (summit depth ≤ 200 m) and seagrasses both achieved over 60% protection. Maximizing protection for features like these became more achievable because of their narrow distributions and because such features often had a high degree of overlap with other conservation features.

Outputs from this algorithm-led exercise suggest that a relatively modest area of marine protection, 23.7% of ABNJ, would be required to extend this minimum of 30% protection to all of the conservation features we included. It is important to note, however, that this is an extremely conservative minimum estimate. Conservative approaches for biodiversity conservation are poorly advised in a global ocean ecosystem that is subject to stochastic disruption, may face uncertain responses to emerging industries in ABNJ (e.g. ocean mining), and is becoming increasingly stressed by climate change [20,92]. As a specific example, the solution derived from this process affords only the minimum level of protection (i.e. 31%; Fig. 2) for the hypothesized future (year 2100) distribution of ABNJ corals. These corals include a suite of foundation building species that promote biodiversity and fisheries health. Corals are also hyper-vulnerable to multiple climate change impacts, such as ocean acidification and warming [93], and thus likely merit more than 30% protection.

The sensitivity analysis exploring a range of percent targets (Fig. S3) suggests that protecting 30% of the spatial extent of ABNJ would, for example, result in a minimum of approximately 37% protection for conservation feature targets. This added buffer could provide additional security for the sustained stable management of the more sensitive elements of biodiversity and resources in ABNJ.

In this approach we do not explicitly model connectivity, which is likely to be important to ABNJ conservation [94]. There are a variety of ways that considerations of connectivity could, in the future, be drawn into this type of analysis. For instance, criteria for minimum MPA size

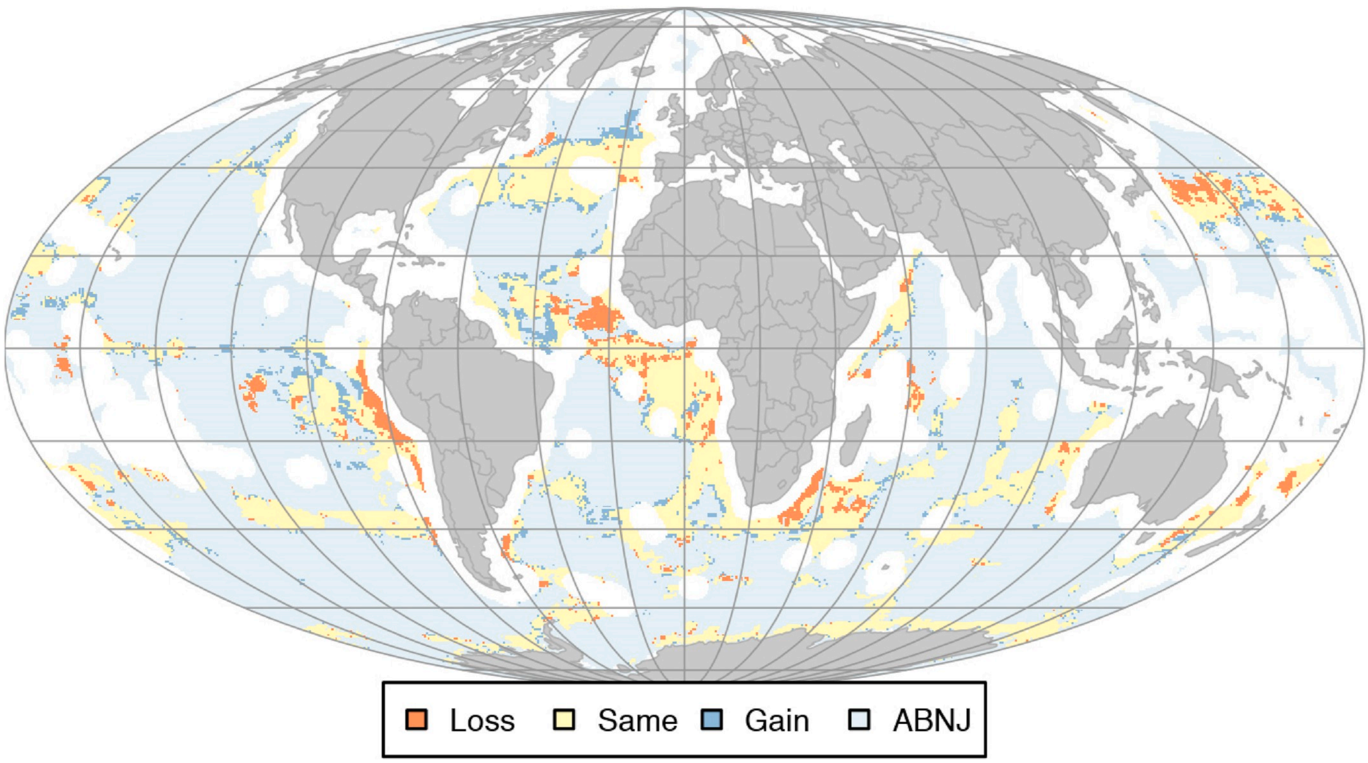

Fig. 3. Influence of fishing effort as a cost in the prioritization process for protection of marine areas beyond national jurisdiction (ABNJ). This map compares model outputs that used fishing effort as the cost layer to a distinct model output that used uniform planning unit area as the cost layer and did not consider fishing effort. Orange indicates regions that were dropped from the MPA solution when the model was parameterized to avoid areas of highest fishing effort. Dark blue indicates areas that were added as the model sought to identify new high priority regions for protection to counterbalance the loss of valued high fishing effort areas. Yellow indicates areas that were part of the planning solution regardless of whether fishing effort was included as the cost layer. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

can be drawn from adult movement ranges and spacing between MPAs based on larval dispersal ranges [95–97]. Considerations of connectivity may be especially important in light of climate change [98,99]. ABNJ protected areas could be networked together to create stepping stones to facilitate species and ecosystem migration using network flow theory or other tools [25,100]. The process of linking together ABNJ priority regions to promote connectivity would, however, necessitate a substantial increase in the amount of ABNJ area required for protection above the minimum area estimates we report. Such analysis is also limited by relatively poor knowledge of adult movement and larval dispersal ranges for species present in ABNJ.

The relative geographic evenness observed in the distribution of the ABNJ regions highlighted by this analysis presents an opportunity to create a global network of MPAs that has ecologically meaningful representation in different oceans, that includes different marine biomes, and that may more evenly distribute biodiversity benefits to regional ABNJ stakeholders. Along the mid-latitudes there was a slight bimodal peak in the percentage of ABNJ included in the model solution (Fig. 1). This aligns with other global marine biodiversity studies [101], especially those focusing on open-ocean [72] or deep-sea species where carbon export flux has been attributed to the bimodal pattern of benthic species richness [81].

Results from this planning exercise appear to show generally good alignment with O'Leary et al., 2019 [102], another recent analysis that used alternate methods and datasets to highlight priority regions for spatial protection in ABNJ. O'Leary et al., 2019 rely on Marxan as a planning tool, whereas we use the *prioritizr* algorithm. Other notable methodological differences include: O'Leary et al., 2019 used sea surface temperature variability to assay areas of climate change resilience and risk whereas we use forecast models to predict climate change-driven shifts in species distributions, our analysis draws on distribution data for a larger number of marine species (12,013 species), and O'Leary et al., 2019 incorporates additional data on biogeographic pelagic provinces that we did not include. In addition, we calculated targets by taking 30% of the summed values of all cells for each conservation feature while O'Leary et al., 2019 calculated targets by taking 30% and 50% of the spatial extent of each conservation feature. Despite these differences in approach, both analyses highlighted ABNJ regions of importance such as the west of Africa associated with the Benguela and South Equatorial Atlantic Currents, portions of the North Atlantic Current, Northeast Pacific, Arabian Sea, nearshore Antarctica, and regions off west of South America including the Salas y Gómez Ridge. There are also ABNJ regions where the outputs do not align, due to differences in methodologies. For example, O'Leary et al., 2019 prioritizes larger swaths of the Southern Ocean and Antarctic Polar Front, while our results include more of the Agulhas Front, the eastward extension of the Agulhas Current in the Indian Ocean. The differences in methodologies and data used provides for a rich opportunity to compare outputs and take an ensemble approach to identifying priority regions for protection in ABNJ.

4.1. Influence of fishing effort data

Including areas of high fishing effort as a cost layer into our analysis shifted the candidate MPAs away from these areas of high fishing effort, as intended. Overall, the effect of including fishing effort had a relatively minor influence on the algorithm's determination of the ABNJ conservation solution. A total of 73% of the ABNJ conservation solution remained the same when comparing the solution with and without fishing as a cost (Fig. 3). When the algorithm treated fishing effort as a cost layer, some ABNJ regions were excluded from the solution such as areas near the Humboldt Current (along the EEZ boundaries of Peru and

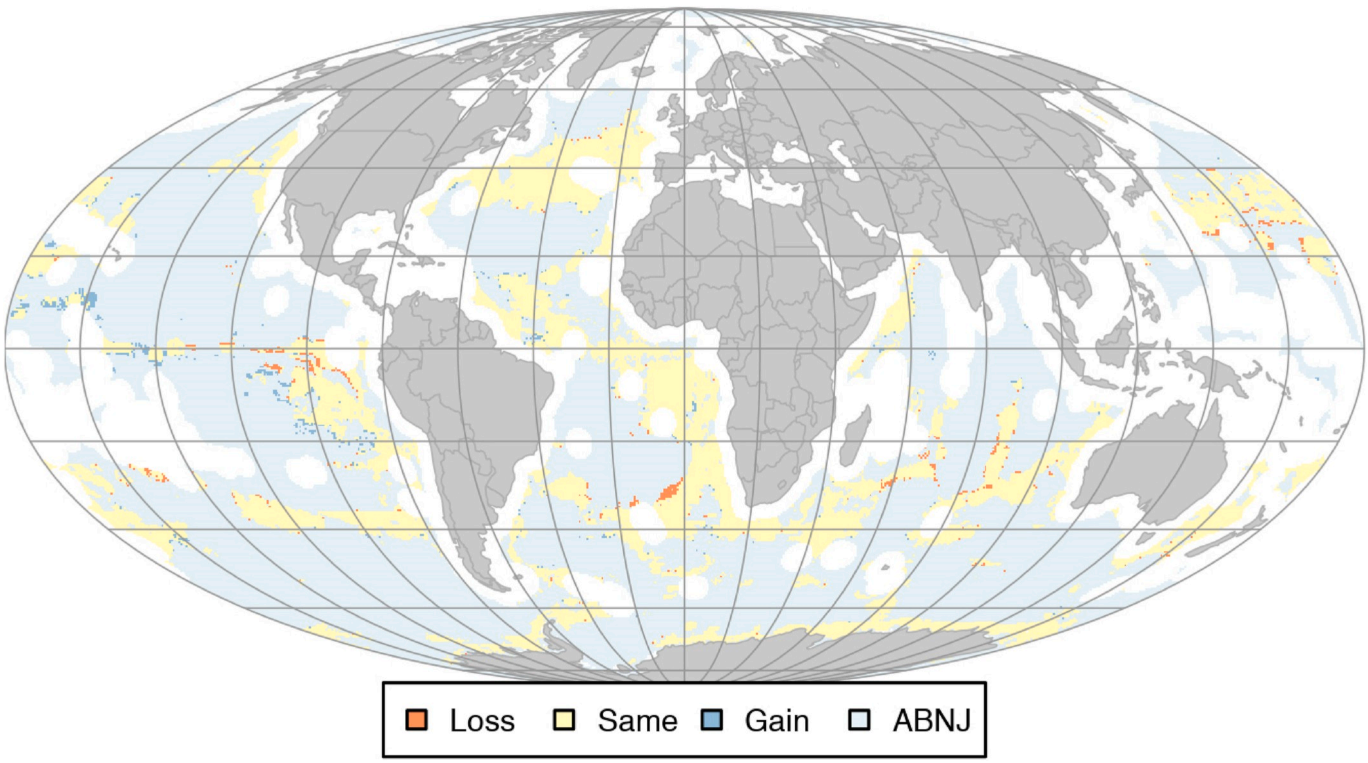

Fig. 4. Influence of climate-biodiversity forecast data as additional targets in the prioritization process for protection of marine areas beyond national jurisdiction (ABNJ). This map compares conservation planning model outputs without versus with forecasted future (2100) biodiversity as an additional set of conservation feature target layers; both include contemporary biodiversity. Orange indicates regions that were dropped from the planning solution when the model was parameterized to include both contemporary and forecasted future biodiversity data. Dark blue indicates areas that were added as the model sought to identify new high priority regions for protection to offset loss of orange areas. Yellow indicates areas that were part of the planning solution regardless of whether forecasted future biodiversity data were included. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Chile), areas off of West Africa, areas along the EEZ of South Africa, and ABNJ waters near Japan. These high fishing effort areas that were excluded host relatively high levels of biodiversity and habitat heterogeneity necessitating that the ABNJ region added to the solution by the algorithm to compensate and still meet minimum conservation targets was slightly greater than the area excluded (Fig. 3). Although the overall percent change in the ABNJ conservation solution after the inclusion of fishing effort was low relative to the size of the entire ABNJ study region, the shifts could be quite significant when considering them in a regional context, especially because many of the areas excluded from prioritization because of fishing effort are close to EEZs.

It is common in marine planning processes to follow this model of avoiding areas heavily used by fishing when establishing new MPAs. When taking this approach, if high priority areas for protection are identified in a way that minimizes overlap with heavily fished areas, this may reduce real or perceived negative socioeconomic impacts of MPAs, which may in turn make it more politically feasible to implement and achieve actual protections in those regions. However, an alternative planning goal could be protection of heavily fished and consequently potentially heavily stressed areas in order to replenish fished stocks and reduce threats to biodiversity. In the particular case of ABNJ, some have argued that efforts to maximally enable ABNJ fisheries would yield only marginal benefits for the protection of global food security given that ABNJ plays a minimal role in total marine food production and ABNJ harvest is strongly controlled by more wealthy nations that can afford the larger ship transit costs [50,91,103]. This analysis also does not account for the potential spillover benefit of MPAs and therefore, it is possible that there will actually be little to no cost to the fishing industry from MPA establishment [50].

Regardless of the approach adopted, given that the majority of ABNJ would likely remain unprotected, it appears clear that MPAs must be directly coupled with responsible fisheries management in order to be effective [104–106]. While there is a recognition that fishing has the greatest impact on biodiversity in ABNJ and there is a growing consensus among negotiators that fish should be included within the new BBNJ agreement, the topic is still being discussed within the BBNJ negotiations. Scientists and legal experts have argued that including high seas fish biodiversity within the BBNJ agreement will be critical to filling key governance gaps [107,108].

4.2. Influence of climate change data

There is no ambiguity that the distribution of ocean biodiversity is already and will continue to be affected by climate change [20,39,109]. Information on the forecasted future distributions of ABNJ biodiversity were included, along with contemporary distributions, as conservation features in our model. With this parameterization, the planning algorithm endeavors to find a conservation solution that will protect biodiversity both today, and at the end of the century, as climate change advances. Inclusion of the currently available 2100 distributional forecast products had a relatively minor influence on the ABNJ regions that were prioritized in the conservation solution (Fig. 4). This, interestingly, suggests that there may not be a strong tradeoff in ABNJ between setting up MPAs to protect contemporary species distributions versus future species distributions. In other words, this analysis suggests, at least for ABNJ, that MPAs implemented today based on current ABNJ data will likely continue to be useful for protecting biodiversity in the future. Because this analysis optimizes protection for areas with high numbers of species (e.g. high species richness) it is important to note, however, that these MPAs may not protect the same species as range shifts occur in the future. In addition, the contiguous areas highlighted in this conservation solution are relatively large, and therefore may more easily capture the ranges of species both now and in the future under climate change. If smaller MPAs were instead implemented, these dual benefits might become diminished.

We also emphasize that climate change associated forecasts for the future distribution of marine biodiversity rely on many assumptions and are rapidly improving. As these forecast models (both climate models and biodiversity response models) improve and are tested against empirical data of species range shifts, these updated data assets can and should be drawn into this ABNJ conservation planning process in an iterative fashion.

4.3. Exemplars of priority regions for protection in ABNJ

The ABNJ areas that were highlighted in this process as potentially deserving of protection were selected by the conservation planning algorithm for a diverse set of reasons. The solution highlighted both shallow water (i.e. < 100 m) and deep water ABNJ regions. While the shallow water candidate MPAs represented only a very small proportion of the overall solution, they were especially species rich and included high proportions of habitat-forming species. The Mascarene Plateau, for example, a shallow water rise coming to within 20 m of the surface located to the east of Madagascar, included planning unit cells with up to 3000 species, including large tracts of seagrass and shallow water coral reefs [110]. The ABNJ region along the Mascarene Plateau has also been highlighted in other analyses as an area of special significance with respect to its high degree of connectivity with coastal EEZs of multiple lower-income nations and the potential this strategic area confers in enhancing within-EEZ ecosystem services [90]. It is worth noting that the marine governance of shallow water regions, like the Mascarene Plateau, can often be more complicated than deeper water regions as a result of continental shelf claims or other considerations [111–113].

A number of the candidate ABNJ MPAs highlighted in this exercise were associated with the presence of high levels of benthic habitat heterogeneity, seamount chains, and/or hydrothermal vent fields. Examples of these kinds of regions include the Emperor Seamount Chain in the northwest Pacific, Salas y Gómez Ridge and Nazca Ridges originating west of Chile, the Walvis Ridge west of Namibia, the Lord Howe Rise between New Caledonia and Australia, the Corner Rise and New England Seamounts in the north Atlantic, and hydrothermal vents of Juan de Fuca Ridge in the northeast Pacific. Protection of regions such as these would provide protection for the physical habitats themselves, as well as for the high levels of species diversity and endemism that either permanently reside (e.g. deep-water corals) or are seasonally attracted to these features (e.g. marine mammals and sea turtles).

Another general class of candidate ABNJ MPAs highlighted in this exercise were found in association with regions of high productivity. Examples include the portion of the Costa Rica Dome highlighted to the west of Costa Rica and Nicaragua and areas of peak productivity in the high seas along the west of Africa associated with the Benguela, Guinea, and South Equatorial Atlantic Currents. These global hotspots of productivity, often driven by upwelling, are also often global hotspots of biodiversity.

4.4. Overlap with “Ecologically or Biologically Significant Marine Areas”

Generally, there was a notable amount of overlap between the ABNJ regions highlighted as high priorities for protection in this planning exercise and areas previously identified by experts in the EBSA process as ocean spaces that have special importance with respect to their ecological and biological characteristics. Approximately 83% of all of the 64 EBSAs that intersect ABNJ shared at least some spatial intersection with the solutions advanced in this analysis (Fig. S2). In some cases, the degree of overlap was high. For example, five EBSAs had 100% area overlap with our solution: the Coral Seamount and Fracture Zone Feature, East Broken Ridge Guyot, Fools Flat, Rusky, and the Juan de Fuca Ridge Hydrothermal Vents. Three additional EBSAs had over 75% area overlap: the New England and Corner Rise Seamounts, Walvis Ridge, and the South Tasman Sea. The spatial concordance between this algorithm-based planning solution and EBSAs was even higher when any overlap was measured against a subset of EBSAs that were identified based on their high levels of biological diversity. Future efforts that may model separately regions of pelagic and benthic importance may further enhance the capacity to compare algorithm-created prioritization outputs to EBSAs that may have been defined specifically because of their pelagic or demersal value.

In some regions there was no overlap between outputs from this exercise and EBSAs. Given that the EBSA process is still unfolding (i.e. some regions in ABNJ have not yet held an EBSA workshop), future regional efforts may lead to the identification of new EBSAs in these areas. The lack of overlap between our planning solution and EBSAs should not be viewed as a deficiency in the EBSA process or of our methodology, as these two planning exercises use different definitional criteria. Both approaches consider, for example, biological diversity, productivity, and species risk, but only the EBSA process considers uniqueness or rarity and only our analysis explicitly includes climate-driven species distributional shifts and attempts to avoid areas of high fishing effort. We suggest that EBSAs not highlighted in this exercise (e.g. EBSA regions defined for their rare or unique features) should also be potentially viewed as areas of critical importance. We suggest that future empirical and theoretical research should explore why solutions highlighted only through this process did not surface in the EBSA process, and vice versa.

Overall, it would seem prudent to place special emphasis on the many ABNJ regions that were highlighted in both this data-dependent exercise and the expert-driven EBSA process. The insight derived from comparisons of this type highlights the value of considering hybrid approaches to MPA planning that include both quantitative evaluations and expert elicitations.

4.5. Proximity to exclusive economic zones

The regions highlighted by this model as candidate ABNJ MPAs contact nearly half (~43%) of all sovereign state EEZs. The top five EEZs that have the most contact with the candidate ABNJ protected areas include Australia, the United States, New Zealand, France, and the United Kingdom (in order of decreasing total boundary length shared).

Considering the proximity of potential ABNJ MPAs to EEZs could be advantageous for MPA enforcement as MPAs that are closer to an EEZ are likely to be easier and cheaper to manage, at least using conventional marine surveillance methods. Effective enforcement has been shown to be key for successful MPA implementation [114].

Evaluating ecological connectivity between candidate ABNJ MPAs and adjoining EEZs can also help to ensure that the major types of services that MPAs can provide (e.g. provisioning of food and nutrition, enhancing fisheries jobs and revenue, protecting marine cultural resources) are maximized for the benefit of coastal states. Enhancing the flow of these benefits may be especially important in lower-income nations [90]. While, as noted above, there is considerable contact between higher-income nations with large EEZs and these candidate ABNJ MPAs, we note the considerable overlap with lower-income nations. Nearly half (~45%) of the sovereign EEZs that had some intersection with priority regions highlighted using this modeling exercise were lower-income nations. Because lower-income nations often have less direct representation in ABNJ fisheries and consequently may be less direct beneficiaries of benefits from ABNJ biodiversity, there may be value in considering how ABNJ MPAs bordering their EEZs, such as those highlighted here, could add value and benefits to their own national waters [91].

4.6. Caveats

The methods we utilize in this analysis represent just one approach for highlighting strategically important regions of ABNJ. The same general approach we employ here can be used as a flexible and transparent platform upon which to explore alternative planning perspectives; e.g. via the incorporation of alternate conservation feature data or the utilization of different *prioritizr* planning algorithm objective functions. This analysis can and should also be iterated upon as new data assets become available.

Some of the alternative scenarios that could be explored using this same conservation planning framework include scenarios that exclusively prioritize the conservation of benthic biodiversity, scenarios that promote carbon storage potential, or scenarios that maximally promote food production in ABNJ. While this prioritization analysis was conducted at the global level, the same process could be reapplied at the regional level (e.g. by confining the planning process to ocean basins, different biogeographic regions, International Hydrographic Organization marine regions, or Regional Fishery Management Organization areas) to highlight solutions that are more reflective of local maxima for conservation targets and fishing effort. Alternative cost scenarios can also be explored, such as using the spatial distribution of fishing profits, rather than effort, as the cost layer. One could also consider applying a boundary penalty within *prioritizr*, which favors solutions with planning units clumped together into contiguous areas that would be easier to delineate and manage. There are additional objective functions, constraints, and penalties that can be applied within *prioritizr* depending on stakeholders' objectives.

It is also important to point out that even within the current implementation of this ABNJ MPA planning process, there are a variety of decisions to be made regarding data utilization that can influence the candidate ABNJ solution we produced (Fig. 1). For example, in this implementation we elected to clump the 12,013 species that exhibit some overlap with ABNJ into 23 taxonomic groups, each of which was equally weighted within the conservation planning analysis. However, because of this taxonomic grouping, this approach does not guarantee that the ranges of all 12,013 species are represented in the proposed MPAs. This species pool could be split more finely or clumped more coarsely, or the weightings could be adjusted to reflect different value sets. In our analysis, we adopted this relatively middle of the road approach to balance the primacy placed on species richness and species evenness in MPA solution building. Similarly, in this exercise we elected to utilize a summary score to represent species endangerment in any given cell rather than to represent endangerment using an index score standardized by the number of species assessed for endangerment in any cell [73,74,115]. This decision to focus on summary endangerment scores emphasizes regions where placement of MPAs would protect the greatest number of at-risk species across ABNJ versus use of an endangerment index which would highlight areas with disproportionately high levels of endangerment and presumably high levels of local biodiversity threat.

There are also many post-hoc filtering rules that could be further applied to shape the outputs from these analyses to meet additional planning objectives. For example, additional weighting could be applied to particular regions in a solution to help mitigate ABNJ resource conflict (e.g. international marine peace parks), especially as may be exacerbated by climate change [91,116].

As discussed alongside our comparisons to EBSA regions, our approach largely considers biodiversity as a key conservation feature, and thus may not prioritize unique, rare, or fragile areas also deserving of protection. Furthermore, we do not explicitly consider the special importance of some ABNJ regions to species' life history stages (another EBSA criterion not assessed in this analysis) that are known to have a shaping influence on population dynamics, such as breeding, foraging, or migrating areas [117–119]. Advancements in wildlife borne biologging [120] and sharing of movement data, in particular, are providing a rapidly improving globally standardized view of where such ABNJ regions with associated life history importance are located. Inclusion of such data will improve future iterations of this analysis.

In this analysis, we focus on how our results could shape the design of MPAs fully closed to extractive activities in ABNJ. However, our results could also provide insight for the design of alternate area-based conservation measures and tools, such as Particularly Sensitive Sea Areas, area fisheries closures or gear restrictions, Areas of Particular Environmental Interest, Emission Control Areas, and mobile MPAs [121,122]. Such measures could provide additional strategic protection of key biodiversity resources in ABNJ. Future work that examines patterns of overlap between the ABNJ priority regions highlighted in this analysis and potentially stressful anthropogenic activities, beyond fishing, in ABNJ (e.g. seabed mining, shipping) could help to shape decisions about the best spatial management interventions to implement in any given area.

We further acknowledge that there are many potential shortcomings of this approach important to consider when making use of these outputs. While the quality and quantity of data on ABNJ biodiversity and ecosystems has indeed recently improved significantly, it remains imperfect, is subject to sampling bias from more well-studied sections of the ocean, continues to be shaped by relatively rapid rates of species discovery, and data layers utilized are not fully independent of one another [12,123]. The AquaMaps modeled species distribution data that comprise the biodiversity layers of this analysis are extremely useful for this application because they provide a globally standardized and transparent method assessing relative patterns of ABNJ biodiversity distribution. They are, however, known to contain inaccuracies. Even given these shortcomings, available data used in this analysis may be argued to be sufficiently robust to serve as valuable proxies for the distributions of as yet poorly accounted for species and features, and reasonably depict hotspots of biodiversity importance that would be of value for ABNJ MPA planning. Emerging and future advancements in our capacity to survey ABNJ biodiversity and habitats, such as the use of eDNA sampling [124], autonomous vehicle sampling [125], and improved remote sensing techniques [126], coupled with more traditional biodiversity sampling methods, should help close gaps in some of the data layers used in this exercise and can ground-truth whether indeed there is unique ecological and biological value in the ABNJ regions highlighted by this model.

5. Conclusion

The process illustrated in this analysis provides a tractable, data-driven approach to identifying ABNJ areas especially deserving of protection. The relative simplicity and flexibility of this planning approach provides advantages in the context of international multi-stakeholder decision making in which transparency is valued. While data used as inputs to this planning process are constantly improving, data sources are sufficiently voluminous and rigorous today to support ABNJ planning processes of this type. Initiating planning processes using tools such as these for ABNJ is consistent with the precautionary principle: as ABNJ become increasingly busy and climate-stressed, we can and should use the best available information to better inform thinking on possible placement of ABNJ MPAs, and should ensure that a lack of complete scientific information is not used as an excuse for failing to take conservation action.

The specific ABNJ regions highlighted as top priority areas for conservation (Fig. 1) specifically deserve further attention as conversations about possible ABNJ protection advance. The many regions of overlap noted between sections of ABNJ highlighted by this conservation planning algorithm and areas highlighted independently by experts during the EBSA process perhaps deserve even greater attention, especially since existing ABNJ EBSAs have successfully received multilateral recognition by the adjacent nations in each EBSA region. Overall, this exercise highlights the value of combining insight derived from this data-driven approach with expert analysis and review to ensure that all important places for ABNJ biodiversity are considered for protection. Results from this planning exercise should, furthermore, be compared to outputs from other recent exercises, e.g. O'Leary et al., 2019 [102], that use alternate methods and datasets to highlight optimal solutions for protection of ABNJ biodiversity and resources. Taking an ensemble approach to identify key regions unambiguously deserving of protection is important given the lasting significance of where to place protection [127].

Efforts such as this to systematically align and compare multiple globally distributed datasets on ABNJ biodiversity, habitats and human activity, may not only be useful for MPA planning, but may also help drive forward ongoing research endeavoring to better understand the biological principles that shape the distribution of ABNJ biodiversity. These data can also be used to inform efforts to adapt ABNJ fisheries management outside of any MPAs to minimize deleterious impacts on biodiversity and synergistically reinforce the goals of ABNJ MPAs. Efforts to inform the spatial management of pelagic fisheries may require layers of species distribution more dynamic in time relative to seasonal migratory patterns than the annualized data layers used in this analysis [46,81].

Recent improvements of existing biodiversity-related ABNJ data products and the emergence of new data sources are timely. With a limited amount of time remaining in the UN BBNJ negotiation process, analyses of this type provide a concrete view of how data resources can meaningfully be leveraged to inform where and how ABNJ MPAs could be established to provide the most significant benefits for global and regional biodiversity. The global data-driven prioritization process showcased here also provides a pathway to capture and compare spatially explicit views that represent planning perspectives of different ABNJ stakeholders. The opportunities to maximize the benefits we obtain from ABNJ biodiversity seem only likely to become diminished and constrained as ABNJ itself becomes busier and more impacted. It would seem prudent to use the richness of ABNJ data and the powerful planning tools presently at our disposal to get the most out of ABNJ for people and biodiversity now and into the future.

CRediT authorship contribution statement

Morgan E. Visalli: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Benjamin D. Best:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing - review & editing, Visualization, Resources. **Reniel B. Cabral:** Conceptualization, Methodology, Writing - review & editing. **William W.L. Cheung:** Conceptualization. **Nichola A. Clark:** Conceptualization, Methodology, Writing - review & editing. **Cristina Garilao:** Data curation, Writing - review & editing. **Kristin Kaschner:** Data curation, Writing - review & editing. **Kathleen Kesner-Reyes:** Data curation, Writing - review & editing. **Vicky W.Y. Lam:** Conceptualization. **Sara M. Maxwell:** Conceptualization, Methodology, Writing - review & editing. **Juan Mayorga:** Conceptualization, Methodology, Data curation. **Holly V. Moeller:** Conceptualization, Methodology, Writing - review & editing. **Lance Morgan:** Conceptualization, Methodology, Writing - review & editing. **Guillermo Ortuño Crespo:** Conceptualization, Methodology, Writing - review & editing. **Malin L. Pinsky:** Methodology, Writing - review & editing. **Timothy D. White:** Conceptualization. **Douglas J. McCauley:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2020.103927.

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